PHYSIOLOGY.

The Functions of the Nervous System of the Myriapoda.—The following experiments on the nervous system of the Myriapoda were begun with the intention of continuing them upon some of the other Invertebrates, for the purpose of comparing the different relations. It has been impossible thus far to fulfil this plan, and therefore these results are given rather as preliminary than as complete in themselves.

The animal used in the experiments was the common species (*Lithobius*), and it proved a rather unfavorable subject. But the large *Iulidæ*, which would doubtless have been better, could not be obtained. The Lithobius is very active and quick in its motions, so that it was necessary to perform some of the operations while the animal was under the influence of chloroform. After the operation in most cases, some time, varying from an hour or two, to a day, according to the nature of the experiment, was allowed to pass before observations were made, this allowing recovery from the shock and from the irritation of the wound.

The method of experiment was as follows: a portion of the nervous system was removed or isolated from the rest, or destroyed by a cut or by burning with a loop of very fine platinum wire heated red-hot in an electric circuit. After recovery from the immediate effects of the operation the actions of the animal were observed at intervals until its death. The same operations were again and again repeated, so that the results given represent the observations of a large number of individual cases.

The superœsophageal ganglion consists essentially of a small whitish mass just beneath the dorsal surface of the anterior segment, sending out two lobes transversely, which end in the nerves leading to the eyes, and just beneath these two other lobes extending forward, and giving off the nerves which pass into the antennæ. This ganglion is connected with the ventral cord by two rather thick commissures, which form a very small œsophageal ring. The ventral cord is practically the same in structure throughout its whole length, being a double cord connecting a series of ganglia corresponding to the segments of the body.

The operations upon the superœsophageal ganglion were performed either by removing the head or some part of the ganglion by a cut, or

destroying it by means of the hot platinum wire. These operations give the following results. First, as is well known, the headless trunk shows no volition nor intelligence. If left without external stimulation it will remain quiet, until it dies, just as will the brainless frog. Yet, under stimulation, movements are made which are well coordinated, though not as perfectly so as when the ganglion is present. The trunk will start forward when touched, and will often advance its own length or more before becoming quiet again. But the motion becomes slower and slower until it ceases or until an obstacle is met, and the body is quiet until again stimulated. Some other protective motions may also be shown. The trunk will back away from a sudden stimulation in front, or the portion of the body touched may be suddenly jerked away, as in the normal animal. Further, if turned upon its back it quickly rights itself. All these actions, however, are weaker than when the superœsophageal ganglion is present, and are not performed with so much precision. The coordination of the motion of the legs is less exact, consequently the advance of the trunk is much slower, and sometimes when it is overturned several attempts are made before it succeeds in righting itself.

Another fact which is noticeable in regard to the superœsophageal ganglion, when a part of the ganglion is destroyed by the hot wire, is that the amount of influence exerted by the ganglion appears to depend on the amount of it which is left intact. A slight burn destroying only a small portion will leave the animal only a very little less active than the normal, while if the larger portion of the ganglion be burned out it is hard to distinguish the subject as regards its actions from the headless trunk. Between these two extremes there are all degrees of difference, so that it appears impossible to set any definite limit between the reflexes of the headless subject and the animal with the greater part of the superœsophageal ganglion destroyed. Moreover, the probable occasional presence of internal stimulation from the wound complicates the matter still further. Where a portion of the ganglion remains the motions continue a somewhat longer time than in the decapitated subject, and often before perfect quiet ensues, isolated motions of different legs occur at longer and longer intervals. In fact, in the two cases there seems to be an analogy to a delicate machine. In the first case, the decapitated trunk, the machine is set in motion by the stimulation but after a time comes to rest. In the second case the adjustment is more perfect and a longer time ensues before motion ceases. The delicacy of adjustment increases with the

amount of the ganglion present, until motion may be caused by stimuli so slight or of such a nature that they are not apparent.

The objection to which all experiments of this nature are more or less open may be raised here: viz, that the mutilation which is unavoidable in the operation would cause weakness and perhaps an apparent loss of function, even if no absolutely essential portions of the nervous system were removed. However, where the superœsophageal ganglion is not involved, the animal endures mutilation to such an extent without losing its volition and activity that the influence of the ganglion must be real and not apparent. Moreover, there is another fact which proves that the ganglion exercises a real influence. This fact is the presence of the so-called "forced motions" after an asymmetrical operation upon the ganglion. In all such cases the animal turns toward the uninjured side as it crawls, and thus goes about in a circle. This circular forced motion can be induced by a burn upon one side of the ganglion, and also by removal of one-half of the head with a pair of fine, sharp scissors. The animal recovers from the latter operation, and sometimes lives for twenty-four hours. The degree in which the forced motion is evident varies considerably. In some cases the diameter of the circle in which the animal moves is not more than an inch, while in other cases it is six or eight inches. The tendency to move in a circle appears to increase in strength as the animal becomes weaker, until sometimes, when nearly dead, it lies upon one side and turns within its own length. Two cases were observed in which the animal turned toward the injured side. In both these the operation was a burn on one side of the superœsophageal ganglion. Owing to accident the observations in both cases were not continued beyond the first so that the later phenomena are not known, but it seems probable that these forced motions resulted from irritation in the wound. A number of attempts were made in large specimens to cut one of the œsophageal commissures, but, owing to the extremely small œsophageal opening, and the small size of the animal, they were not successful. Steiner in a short article published a year or two since (Die Funktionen des Centralnervensystems der wirbellosen Thiere), states that with his large *Iulidae* he was able to cut a single commissure, and obtained very evident circular forced motion toward the uninjured side.

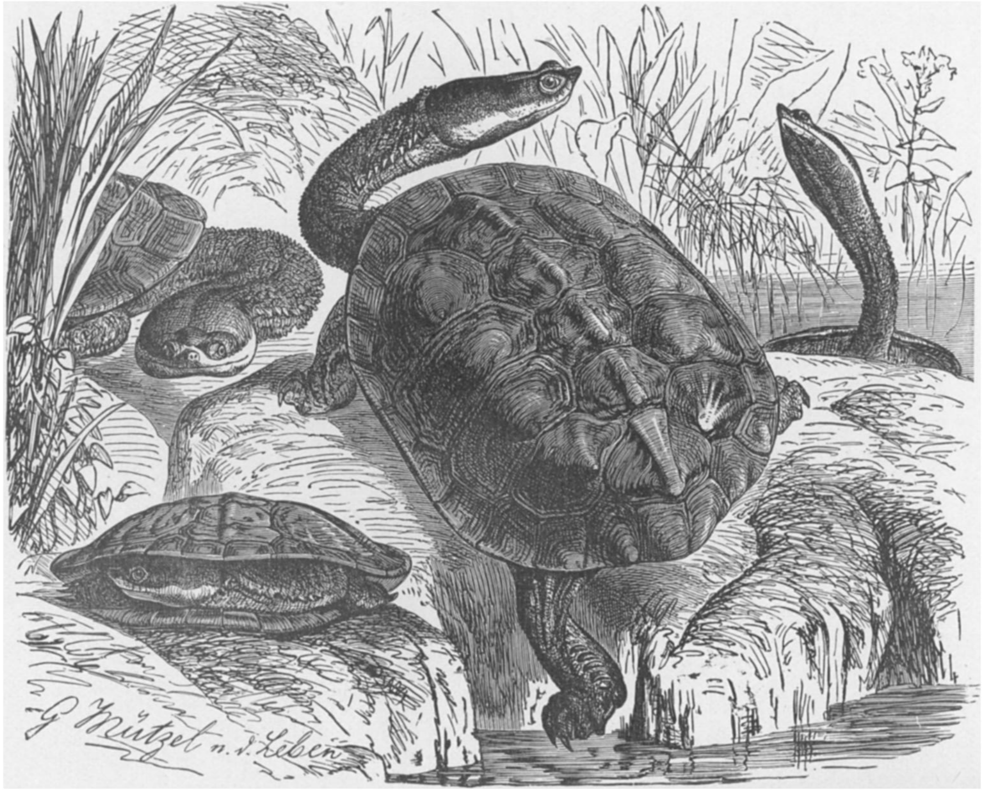
The superœsophageal ganglion, then, is a motor center to which all the motor centers lying in the ventral cord are subordinated. It enables them to respond to sensory stimuli with greater exactness and strength than would otherwise be possible. Besides this it is evidently

the center of the sense of sight and the sense of touch in the antennæ, and, moreover is the seat of whatever intelligence the animal possesses. The direction of the forced motion toward the uninjured side indicates that the fibers from the ganglion cross to the opposite side in their course. This crossing must take place in the extreme anterior portion of the ventral cord.

A part of the functions of the ventral cord are shown in the decapitated trunk. As stated above the power of coordination of motions remains to a large extent, and the animal is able to right itself when overturned. The decapitated trunk is, moreover, very sensitive to various external stimuli. A light breath of air will often set it in motion, and if the hot wire be held within one eighth of an inch the heat is usually sufficient to cause quite violent movements. This extreme sensitiveness to heat is very marked in all cases.

If now the different portions of the cord be examined, it appears that it is practically the same in function along its whole length. If a decapitated trunk be cut in half, both portions show about the same degree of activity, and neither varies much from the whole trunk except that in these smaller portions death ensues more quickly. Either of the two halves when overturned makes very evident attempts to right itself, but usually does not succeed because it is too short. If each of these halves be again cut in half, each of these pieces can still be made to advance by means of stimulation. When placed on the back some slight movements are seen which soon cease, and the piece remains perfectly quiet until again stimulated. Further than this the sense of equilibrium cannot be traced. It requires the presence of several segments in order to manifest itself. Whether, if the weakening effects of the shock and the extreme mutilation could be avoided, it would assert itself with the presence of a single ganglion cannot be definitely stated. It is, however, more probable that the coordination of more than one is necessary. The power of advancing when stimulated is still evident in a piece which possesses only three pairs of legs; a piece with two pairs of legs when stimulated makes movements, but apparently has not sufficient strength to advance. Portions of the trunk from the anterior and posterior part of the body appear about alike in these respects. Various other methods were employed in the examination of the cord, such as cutting or burning through the cord without severing the body, or destroying the superœsophageal ganglion without removing the head. They all lead to the same conclusions in regard to its functions.

PLATE XXXI.



Hydromedusa tectifera. The snaked-necked turtle.

The nervous system of the earwig, then, consists of, first, a series of centers which are capable, unaided, of responding to sensory stimulation by appropriate coordinated motions, in other words, a series of complex reflex centers lying in the ventral cord; and second, of a single ganglion situated in the head to which all the reflex centers are subordinated, and which contains also the centers for the eye and the antennæ, and the seat of whatever intelligence may be present. Steiner (Die Funktionen des Centralnervensystems und ihre Phylogenese; Zweite Abtheilung: Die Fische) regards a true brain as defined by the presence of a general motor center together with the centers of at least one of the higher senses. The superœsophageal ganglion according to this definition is a brain, and indeed Steiner so regards it. The ventral cord is analogous in function to the spinal cord of some of the lower vertebrates, being a series of coordinated reflex centers, with perhaps some automatic functions also, all of which are subordinated to the brain.

Some experiments of a similar nature were performed upon the Decapoda, but were not continued far enough to give any definite results except that, as would be expected, the superœsophageal ganglion is a brain, and that of the ventral portion of the nervous system the thoracic ganglion is the highest and most complex in function.

A few experiments upon the horse shoe crab (*Limulus polyphemus*) revealed the fact that the presence of the chain of small ganglia running backward, or even of part of it, even when entirely separated from the rest of the nervous system was sufficient to cause regular normal motion of the gills, which continued in some cases for two days, if the animals were left undisturbed in water. The motion usually ceases when the gills are exposed to the air or when they are suddenly stimulated but in a few moments the motion begins again if they are again covered with water.

The results here given are not all new, but it is hoped that the statement concerning the more simple functions of the nervous system of the Lithobius may serve as a basis for further work, and for comparison with the results obtained from other Invertebrates.

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